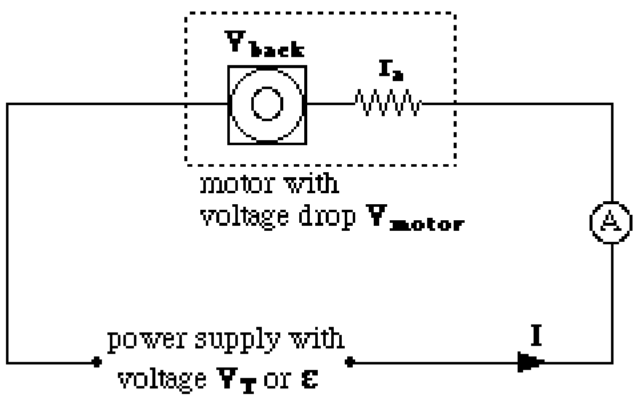
Back EMF in a Motor

An electric motor has the same design as a generator; the latter changes mechanical energy to electrical energy and the former, vice versa.

- A current in the armature of a motor turns in the magnetic field according to the **RHR**, with $\mathbf{F_{mag}}$ creating the necessary torque.
- BUT the turning armature, by the nature of its motion in the field **B**, has an EMF induced in it (just like a generator).
- As expected, this EMF opposes the voltage of the source that created it; that is, the motor becomes a generator as soon as it is turned on, and the opposing (or counter, or back) EMF will increase with increasing frequency.
- However, the applied EMF overcomes this "reverse emf" and makes the current flow in the direction suggested by the applied EMF; in effect, the reverse EMF acts as a *brake* on incoming current and limits it.

Now examine the following schematic diagram:



The only load in this circuit is a motor with a voltage drop $\mathbf{V_{motor}}$. Meanwhile, if the motor is plugged into an electrical outlet, then the voltage supplied is the **EMF** provided by BC Hydro. By inspection of the diagram, we see that the voltage supplied by the power supply must equal the voltage drop in the motor, or

$$\mathbf{V_{motor} = \varepsilon}$$

Note that this voltage drop in the motor $\mathbf{V_{motor}}$ is caused by *two* factors:

- the relatively small resistance in the armature $\mathbf{r_a}$, which produces a voltage drop equal to $\mathbf{V_a = Ir_a}$
- the *back* EMF produced by the rotating armature ($\mathbf{V_{back}}$) which also acts like a voltage drop.

Therefore, the total voltage drop across the motor $\mathbf{V_{motor}}$ is $\mathbf{V_{motor} = V_{back} + Ir_a}$

→which can also be written as $\boldsymbol{\varepsilon} = \mathbf{V_{back} + Ir_a}$ (remember, $\boldsymbol{\varepsilon} = \mathbf{V_{motor}}$)

Note that this equation tells us that the power supplied by BC Hydro will ***always*** deliver more voltage than the back EMF produced by the motor. It can also be re-arranged to read

$$\mathbf{V_{back} = \boldsymbol{\varepsilon} - Ir_a}$$

→which is what you see on the formula sheet.

Example #9: A motor operating at full speed draws a current of 4.0 A when connected to a 110 V source. If the motor has an armature resistance of 3.5 Ω, what is the back EMF at full speed?

(see Induction Ex 9 for answer)

In this example, emphasis was placed on the motor operating at full speed. In fact, the back EMF varies *directly* with the frequency of rotation, so that if the armature is rotating at less than full speed, $\mathbf{V_{back}}$ decreases. This causes less overall resistance in the circuit, so that the current will *increase*. Even worse, if the motor's armature is jammed so that it can't turn at all, then:

$$\mathbf{V_{back} = 0} \qquad \text{and} \qquad \boldsymbol{\varepsilon} = \mathbf{Ir_a}$$

This is not a good thing:

- if the resistance in the armature is small, then the current running through it will be high;
- the power lost to heat ($\mathbf{P = I^2r_a}$) will be much larger; in fact, the motor will likely overheat as a result.

Example #10: A 120 V dc motor has an armature resistance of 5.0 Ω and draws 6.0 A when it is operating normally.

a) What is the starting current of the motor just before the armature begins to turn

b) What is the back EMF when it is operating properly?

(see Induction Ex 10 for answer)

Finally, you must remember that if the power source is a battery, the ***terminal voltage*** $\mathbf{V_T}$ must be used in place of ε in the motor equation.

Example #11: A power supply of EMF 6.0 V and internal resistance 0.50 Ω is used to run a motor. When the motor is jammed, the current is 3.0 A, but when it is allowed to run freely, current is 1.8 A.

a) What is the resistance of the armature of the motor?
b) What is the back EMF of the motor when running freely?

(see Induction Ex 11 for answer)

In terms of overall power used in a motor:

Power supplied = heat in armature + mechanical power output

- or, $\mathbf{IV_T = I^2r_a + IV_{back}}$

The efficiency of a motor can be determined based on its output power compared to power supplied.

Example #12: Determine the efficiency of a motor which has a back EMF of 8.0 V when a source voltage of 12.0 V is supplied.

(see Induction Ex 12 for answer)